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ABSTRACT

Rapid and radical changes taking place in the scientific, technological, educational, and societal context are affecting the education and training of engineers. To ensure that engineers keep pace with change, reappraisal and revision of the curricula is considered necessary. Unesco established and sponsored the International Working Group on Engineering Curriculum Design with the aim of initiating and facilitating investigation and communication into the curriculum design process. This paper identifies factors which influence the curriculum design process in engineering education. A methodology of engineering curriculum design is discussed and its main stages are described. Some conclusions and recommendations for further investigation in engineering curriculum design are also made. (Author/MA)

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CURRICULUM DESIGN IN ENGINEERING EDUCATION - PROGRESS REPORT ON THE WORK OF THE UNESCO INTERNATIONAL WORKING GROUP

SUMMARY

The paper identifies factors which influence the curriculum design process in engineering education. A methodology of engineering curriculum design is discussed and its main stages are described. Some conclusions and recommendations for further investigation in engineering curriculum design are also made.

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I. INTRODUCTION

Rapid and radical changes are now taking place in the scientific, technological, educational and societal context affecting the education and training of engineers. At the same time it is recognised that engineers have played a major role in the impact which these changes have wrought on society. In order to ensure that engineers now and in the future can keep pace with these exponential developments, and are capable of meeting the challenges confronting them, it is necessary continually to reappraise engineering curricula and to revise and renew them to meet objectives defined by the changing situations.

The education and training of all levels and types of engineer involves the acquisition and mastery of certain knowledge, skills and attitudes. Although the emphasis placed on each of these attributes may vary between nations and within the engineering professions, all engineers will require them in some measure in order satisfactorily to serve their society, their profession and themselves. The knowledge required is scientific and technological and can be both general and specialist. The necessary skills include analysis and synthesis, experimentation, a capacity for team work, communication and management. The attitudes involve the engineer's personal characteristics such as integrety, responsibility and creativity, as well as an awareness of, and concern for, the well being of the individuals and society which he serves.

All engineering courses are designed to provide the necessary attributes but the amount and type of knowledge imparted and the relative importance attached to the different skills and attitudes varies significantly. The diversity which exists between the needs and problems affecting engineering education, training and subsecuent employment in different countries, relates to the state of industrial and economic development, the educational and cultural environments, available and potential resources and many other particular national - or even local -

criteria and constraints. Any of these factors may fundamentally affect the process of deciding the nature and number of engineers who will be required and the duration, structure and content of their programmes of education and training.

It is apparent, therefore, that there can be no easy or universal solution to the problem of reliably identifying and defining the objectives of an engineering education, developing a curriculum to satisfy them and envolving from this a purposeful educational activity. What is possible and necessary, however, is to highlight the need continually to revise and create curricula, and to do this in a systematic and logical way which consciously and effectively relates the engineering curricula to the true needs.

It was in recognition of this that Unesco established and sponsored the International Working Group on Engineering Curriculum Design with the basic aim of initiating and facilitating investigation and communication into the curriculum design process. In particular the group was briefed to emphasise the development of a generalised methodology of curriculum design which would enable all countries to "design in a rational, systematic way curricula that will be appropriate to the particular needs of the countries in terms of their economic and social development".

At an initial Unesco meeting in Tbilisi in 1972, it was concluded that "Because of the continuing evolution of the scientific and technological basis of the work of engineers and their role in society, engineering curricula be henceforth regarded as needing continuing reappraisal in the light of changing circumstances in society, education and industrial employment". It was recognised that engineering had played a major role in the impact which changes in science and technology had made on society, and that in future there would be a continuing process of change in the work of engineers. The meeting demonstrated a great diversity in the methods of designing engineering curricula which reflected differences in the economic and educational systems in different countries. However, it was agreed that it should be possible to develop universal and systematic methods for the revision or creation of engineering curricula.

At a further meeting organised by Unesco in Warsaw (1974) the Working Group also emphasized that the education of engineers is a highly complex task, dynamic in nature and influenced by a variety of factors which can have a significant effect on the final outcome. In order to cater for these characteristics, the Working Group recognized that any engineering curriculum must be flexible and adaptable so that it can be readily adjusted to meet changing conditions and requirements.

The discussion on curriculum design at this meeting confirmed that there was a considerable measure of agreement on the description and definition of the logical sequence of events - and the modelling processes - involved in the design of engineering curricula. The Working Group therefore concluded that it would be possible to develop broad guidelines for the systematic design of engineering curricula. In order to achieve this objective - and also in recognition of the fact that further information was required on the wide range of external factors which influence curriculum design - the Group identified the following four prime areas which were to be studied in detail :

(a) The relationship between engineering curricula and the teaching and learning process ;
(b) The effect of inter-disciplinary courses on engineering curricula ;
(c) The development and description of a methodology of engineering curriculum design ;
(d) The specific needs and problems related to the design of engineering curricula in the developing countries.

At the next meeting of the Working Group in Paris (1975) the participants reaffirmed that a generalized methodology of curriculum design which was sufficiently adaptable and easy to use would be of considerable value both in the development of suitable engineering curricula and as a method of educating those responsible for curriculum development. A simplified diagram of the modified methodology was prepared during the meeting and agreed by the Group as the basis of future work in this area. Because of the nature of the Working Group, the methodology has been developed primarily for curricula aimed at producing professional engineers. However, the Group considered that the methodology developed and advocated was sufficiently general in nature to be applicable also to the development of curricula for the education and training of technicians.

The present paper outlines the progress made by the Group and discusses the areas of study which have been investigated by its members and its programme of current and future work.

2. MAJOR STUDY AREAS OF THE WORKING GROUP

2a. INTRODUCTION

The previous section described how the studies and meetings of the International Working Group and the documents available to it, led to the unanimous view that it was possible to identify and define certain broad principles related to engineering curriculum design which apply to all countries and situations. As a result of the emergence of this view the Group moved towards the development and detailed description of a systematic, semi-formal and less-intuitive methodology of engineering curriculum design which was intended to be realistic, easy to apply and adaptable to all situations.

At the same time it was recognized that other related areas warranted further investigation in order to assess their relevance and importance to engineering education in general, and curriculum design in particular.

The following sections give a detailed account of each of these areas of study and of the evolution and development of the generalised semi-formal methodology of curriculum design which has accompanied them.

2b. THE RELATIONSHIP BETWEEN TEACHING AND LEARNING METHODS AND CURRICULUM DESIGN

The Working Group recognized that the highly complex structure represented by an engineering curriculum has to serve several functions at the same time, including for example the introduction of new material to the student, educating and training the engineer in the proper decision-making process and at the same time developing his creative talents, skills and attitudes.

Whereas in the past curriculum development had focussed on what a student needed to know and acquire, rather than how he learns, the increase in the understanding of the learning and teaching process - although far from complete - was changing this approach. The advances in the teaching-learning sciences are now allowing engineering educators to design curricula that organize the body of existing knowledge in a logical fashion and also provide activities and present the content in a manner that is meaningful to the student.

A review (Ref. 3) of the various theories of learning, classified into stimulus response, cognitive functionalism, psycho-dynamics and probalistic theories emphasized the limitations of these predominantly empirical studies and their applications to certain kinds of learning under certain conditions. The organising principles for the development of curricula and teaching strategies must cover the logical ordering of the subject matter in curricula and such factors as the complexity and hierarchy of the knowledge, its abstration and correlation. The ways in which the student reacts to the material involves principles of continuity, sequencing and integration.

The experience of the USSR (Ref. 10) has shown that the increasing use of computers has had an influence on engineering curricula and that applied mathematics and related subjects have become one of the most important parts of the professional education and training of engineers. The significant changes in engineering education have given rise to such problems as a new sequencing of material in the curriculum and the need to engender and foster a new approach during teaching, project and research. The leading principle for solution of these problems is a principle of continuous mathematical instruction in time and the collaboration between all the involved units of the institute.

It has been conclusively shown by several studies (Ref. 10, 12, 14) that individualised study is one of the most effective methods of teaching and learning although it should be emphasised that this study should be viewed as a complement to - not a substitute for - traditional methods. Also it should be introduced gradually into the more easily understood and isolated parts of the curriculum and its success or otherwise should be continually monitored.

In Finland (Ref. 13) a matrix method has been suggested for optimising teaching methods against the knowledge and abilities : "The method is based for simplicity on the assumption that knowledge and abilities are independent of each other. The knowledge or skills which are identical with the syllabi contribute to the development of the abilities. However, the teaching methods providing the syllabi are more important for the extend to which an ability is developed in the course of a study".

At present there appears to be no established method - other than empirical and intuitive - of relating teaching methods to the necessary abilities and knowledge. The Working Group accepted this and in discussing Ref. 13 expressed additional reservations about the difficulties involved in quantifying such value judgements and subsequently manipulating the values in order to optimise. There was strong agreement, however, that the proposal did emphasize the need to attempt such a correlation and provided some guidance on how it might be undertaken and the results assessed.

Another aspect of the relationship between teaching and learning methods considered by the Working Group was the value of project work and research as a means of reinforcing theoretical studies and encouraging the necessary skills and attitudes.

The discussions on this respect of the work of the Group demonstrated that teaching and learning is an individual process involving the personality, motivations and ability of the student, whereas curriculum design is a mechanistic process which is primarily concerned with the selection and structuring of material. The relationship between these activities is not easily recongized and defined although the motivation as related to proper sequencing in curricula structure is a highly important factor in designing an affective curriculum. The Group considered a suggestion that the stimulus-response theory of learning appeared to be apposite to the inculcation of knowledge, for example the Keller plan approach, whereas the cognitive theory, as illustrated in project work and research, was more appropriate to the development of skills and attitudes. It was accepted, however, that such simplistic correlations could be superficial, particularly in view of the complexity of the topic and the inadequacy of the information currently available.

It was in recognition and support of this view that the Working Group proposed to continue the investigation of the relationship between teaching and learning methods and curriculum design. It was appreciated that the subject was a difficult and complex one, and that no facile and general solution was likely to emerge in the near future, however it was considered that further studies would certainly assist in emphasising the importance of this aspect of curriculum design, and could also lead to the formulation of guidelines to augment the curriculum design methodology.

2c. INTER-DISCIPLINARY COURSES IN ENGINEERING CURRICULUM DESIGN

The Working Group received two contributions concerned with interdisciplinary courses in engineering education. An example from Poland (Ref. 12) describes a system of individual curriculum studies which enables high calibre students who have completed their basic theoretical and technical programme of studies, to structure an interdisciplinary course from existing units. The advantages of providing interdisciplinary programmes in this way, rather than developing a purpose built curriculum, are related mainly to the fact that such programmes are required, at present, for relatively few students. Experience has shown that there are certain safeguards which must be embodied in the system in order to protect the student and ensure his competence. Because of the extra effort and level of responsibility which the individual curriculum studies impose upon the student, it is necessary to select carefully and limit the number allowed to pursue such courses. In addition, it is crucial to the success of the system that it provides for the needs and abilities of individual students and that their progress is closely organised and monitored by the staff concerned.

In Finland (Ref. 13) the development of a unit system enables students to select from certain options in addition to taking compulsory 'core' subjects. Further opportunities to pursue interdisciplinary studies are afforded by a 'free' element in the programme which can be spent taking any course at the parent - or another - university.

The Working Group recognized that there was likely to be an increase in the demand for studies of this type involving engineering, in order to match the increasing complexity and interdisciplinary nature of the problems which engineers would be asked to solve. It also recognized that the proposals offered real advantages in terms of student motivation, staff development and the provision of a few highly motivated and valuable interdisciplinary specialists.

However the experience of some members of the Group - particularly in the implementation of 'Modular' degree courses-indicated that there were serious difficulties in structuring mixed-discipline courses. In the United Kingdom it is becoming customary to differentiate between two categories among these courses which attempt to combine disparate

disciplines. The first is the interdisciplinary course which combines only two disciplines and where the academic standard and scholarship is retained in the level to which each discipline is studied. The second is the Multidisciplinary course in which more than two disciplines are combined and in which the academic and intellectual level and challenge are identified in the inter-relationships which need to be established and defined between the disciplines. The types of curriculum developed to match the aims and objectives of these two categories of mixed discipline courses are significantly different from each other and from a single discipline course curricula. It was also recognized that one of the major problems was to provide the staff who were capable of bridging the disciplines in a way which was meaningful to the students, and of concentration of the interfaces between the disciplines rather than the specialisations.

The Working Group also discussed, in the light of their individual experiences, the problems involved in restricting student choice - this was considered to be necessary for both academic and administrative reasons - whilst still retaining the advantages of individualised courses and student motivation. The view that inter-disciplinary studies in depth should be concentrated at the postgraduate level with only a taste of interdisciplinary problems in the undergraduate course was also considered, together with the proposition that the highly specialised training and perspectives which resulted from an under-graduate course in engineering rendered most students incapable of subsequently becoming interdisciplinary in outlook.

In concluding, the Working Group agreed that further work needed to be programmed in this area.

2d. TOWARDS A FORMAL METHODOLOGY OF CURRICULUM DESIGN

The papers on engineering curriculum design methods from USSR and Venezuela which were discussed by the participants at the Tbilisi meeting in 1972 demonstrate a significant measure of agreement in recognising the rapidly and radically changing situation whithin which curricula development must take place and the need for continual reappraisal and revision ; they also identify the existence of the common and logical sequence of stages involved in any scientifically-based design process.

In reference 1, some tentative proposals are made for methods of quantifying and relating parameters and this is followed by a description of the four main stages in devising curricula as "in the first stage prognosis is made of how the field of sciences or technology could develop ; in the second stage the prognosis is used as a basis for defining separate professions needed in the national economy ; in the third stage, a list is drawn up of subjects for professional education and training and their weighting based on an evaluation of their usefulness ; the fourth stage consists of determining logical correlations between subjects and their sequencing."

Reference 2 stresses the importance of working ab initio, of discarding unnecessary and undesirable constraints and of considering the real and fundamental problems confronting the engineering curriculum design. "The design of an engineering curricula should not be undertaken unless one has the following ingredients : an information base ; a needs' analysis, based on the information gathered ; a problem statement, the requirements and expectations of the programme ; a modelling process in which the parameters of the model can be identified and used later on in the implementation process ; constraints and criteria, both external to the system as well as part of the educational system proper. A synthesis of alternatives can then proceed based on the constraints and criteria that already exist whereby the financial, physical and economic viability of the programme can be established and its efficiency evaluated. By means of experimentation and evaluation it is possible to make a choice and reach a decision on whether to proceed with implementation or to optimize the results by returning to one of the earlier stages of the design procedure. If the process has been successful it proceeds to its final stage of implementation and the useful output of human resources, hopefully in full agreement with the needs based on the information collected".

The general principles agreed at the Warsaw meeting were embodied and expanded in the paper from the United Kingdom (Ref. 4) presented at the Warsaw meeting. This paper describes a methodology of curriculum design based on experience gained during the previous decade in developing, validating and inaugurating a large programme of degree-level engineering courses in the United Kingdom Polytechnics. It proposes a procedure of curriculum design

involving only two stages : problem definition and curriculum development which are broadly classified into needs and constraints and are each discussed in detail and related to the appropriate stage in the overall procedure. The importance of identifying, defining and delineating the real problem is emphasized and somme suggestions are made concerning the collation of the required input data. The authors "have advocated and attempted to define a less formal and routine methodology. This combines the techniques which experience in the United Kingdom has shown to be both viable and successful, with a rational and systematic approach which attempts to make explicit the implicit processes and assumptions inherent in curriculum development".

In presenting the paper, the authors drew attention to the limitations inherent in some methodologies and the danger of total dependence upon any one methodological approach ; the paper suggests the following criteria against which any proposed methodology might be judged.

(i) It must match the situation in which it is to be used, either by being developed specifically for that situation or by being sufficiently adaptable to meet a variety of situations ;

(ii) It should be a means of communication and provide, for the benefit of all those involved, a record of the process and the decisions made ;

(iii) It must be sufficiently flexible to cater for the changes which will inevitably occur as the process develops ;

(iv) It should provide a converging, logical route to a satisfactory solution : although the methodology will normally itself identify and pose new problems as the process progresses it should also encourage and assist in the reduction of the imponderables and the emergence of feasible solutions.

In addition to these positive requirements there are certain characteristics which should not be contained in any methodology :

(v) It should not involve time-wasting related directly to the methodology rather than the curriculum development : for example, the collation and assessment irrelevant date and over elaborate data processing ;

(vi) It must not inhibit originality by being too formalised : it should encourage and assist good judgement and creativity by preparing the ground for them ;

(vii) It must not be disproportionate to the situation in which it is employed.

The need for a more systematic approach to engineering curriculum design was also supported in a paper from U.S.A. (Ref. 3).

"Developments in the learning sciences are providing methods for analysing and designing curricula that give a much better insight into what is taking place and which allow curricula to be developed in a systematic and organized fashion, in a way that can achieve pre-specified goals". The stages in the curriculum design process suggested by the author are : needs analysis and goals ; organization of a curriculum ; selection of content ; selection of learning activities and evaluation.

The Working Group discussions which followed the presentation of those papers demonstrated once again that, whatever its economic, societal and educational context, the curriculum design process contains certain common logical steps, the identification of which defines the methodology. Although there were differences in the descriptions presented - and an acceptance of the limitations identified - these were considered to be primarily matters of emphasis and terminology. The Working Group had sufficient confidence in this view, and the progress which had been made, to allocate as one of its main areas of future work the further development of a methodology and the techniques and aids associated with it.

2e. PARTICULAR PROBLEMS OF ENGINEERING CURRICULUM DESIGN IN THE DEVELOPING COUNTRIES

References 7, 8 and 9, which were prepared and presented by members of the International Working Group, indicated that the problems inherent in engineering curricula design in the developing countries were often similar in nature to those in other countries, but were less tractable because of special constraints and criteria imposed upon them. It was also clear that the diversity of educational environments, criteria and constraints had led to a wide range of engineering curricula between educational establishments in developing countries.

During the discussions on the availability of demographic data relating to the societal needs and priorities which engineering, curriculum design must attempt to satisfy it was pointed out that, though there exist in developing countries national and regional organizations to help and coordinate the task of education planning, in many cases financial limitations and the administrative structure of the institutions exercise greater influence than the purely educational criteria and this is reflected on the design of engineering curricula.

In discussing the information required in order reliably to analyse the needs of objectives of engineering curricula the member of the Group from Nigeria (Ref. 7) states : "It is important to distinguish between the immediate needs of industry and future needs : it is the latter that is of more importance in the educational process. [In Nigeria] the Ministry of Economic Development has a Manpower Board which conducts studies in manpover requirements as part of the Economic Development Programme for the country. This necessitates socio-economic forecasts for the nation and identification in broad terms of engineering manpower needs for five years ahead, at a time. Technological forecasts are important but in the case of developing countries this is largely meaningless because there is no developmental work going on... Manpower forecasts are therefore in general terms and there is no proper study or a needs' analysis to identify specific requirements of industry. A direct consequence is that manpower utilisation is not directly correlated to the needs of industry or the training of manpower".

[In India] (Ref. 8) "One of the important social objectives of education is to equalise opportunities enabling the backward and under-privileged classes and individuals to use education as a lever for the improvement of their economic condition. Though in many ways remarkable progress in equalising opportunities open to students from rural or backward areas and of parents with low income has been made, there are striking variations in the composition of students in different institutions".

The Working Group recognized that a difficult problem faced by the curriculum designer in a developing nation is the necessity to cater for a diverse, and sometimes unprepared student output from the secondary education system. In Egypt (Ref. 9) "The youth of developing countries are in need of being introduced to modern ways of living based today on developed technology. These countries have to encourage practical training, visiting industrial plants, etc... in order to build up a technical background among its youth". The paper from Nigeria (Ref. 7) points out that : "The first generation of Nigerian engineers can hardly be said to have come from homes which provide a suitable background for an engineering career. Mechanical toys were non-existent, the family structure discouraged initiative and there was little encouragement to be inquisitive. It is only when he arrived at the University that the African engineering student made his first acquaintancewith simple tools like the T-square, and for the first time came across words like 'pump', 'rivets', 'beams'."

The lack of an appropriate technical background and the handicap this presents to the student imposes certain constraints on curriculum design. Some countries, such for example as India (Ref. 8) are now introducing changes in the system of secondary education which will affect existing engineering curriculum.

A further problem which is common to all curriculum development but which appears to be exacerbated in developing countries is the need to establish close and fruitful relationships with local industry. This is essential not only because of the necessity to assess the real needs of that industry but also in order to forge and foster a partnership capable of providing the relevant practical training, engineering research and industrial experience which are essential elements in the education and training of engineers.

Increased cooperation and communication between industry and educational institutions is also essential to effect improvements in the professional skills of the teaching staff in the developing countries. It is evident that many engineering educators in these countries have little or no industrial experience and therefore have limited ability to judge by experience the qualities of an engineer required in industrial situations. Possible methods of overcoming these difficulties and of improving industrial relevance and awareness were discussed by the Group ; for example it is possible for teachers to enter industry and work there for limited periods of time, and further improvements in teaching are possible through the utilization of industrial engineers as part-time teachers.

In many industrially advanced countries engineering students have a certain amount of industrial training when they are pursuing their academic studies or when they are admitted to degree courses, while in many developing countries it is tradition for the engineering colleges to give the preliminary practical training mainly in their own workshops and laboratories. However such practical training in the college's workshops is considerably limited, because many of the workshops are rarely developed by including the latest technological practices prevailing in modern industries.

It is now also widely recognized that engineering research as part of the training component is a valuable eeucational tool in helping to lay the foundation for a professional career. Unfortunately in developing countries up to now the amount of research in engineering institutions is often too limited to be helpful. In view of the vital part to be played by engineering research in the training of engineers it is desirable, as is already the case in certain developed countries, that the place of research in engineering institutions in the developing countries should be duly reflected in the teaching process.

3. A PROPOSAL FOR A METHODOLOGY OF CURRICULUM DESIGN

3a. INTRODUCTION

As described in the previous sections there had emerged from all the meetings of the Unesco international Working Group on Curriculum Design a unanimous view that, although no universal engineering curriculum could satisfy the enormous variety of situation, and the rapidly and radically changing needs and constraints affecting engineering education and training, there was sufficient commonality in the methods of curriculum design and the principles and factors involved, to suggest that a generalized methodology of the process could be identified and defined. The papers available to the first meeting of the Group indicated the broad principles involved and the subsequent programme of work expanded, crystallised and synthesised these concepts towards the development and description of an appropriate universal methodology.

Thus the methodology described in the following sections and illustrated in Fig. 1 represents the amalgam of the work and views of all members of the Group. It incorporates, in some measure, suggestions and points of emphasis made by each member and therefore encompasses and caters for a wide range of experiences and environments. Although the Group has now agreed the current description of the main stages in the process, together with the terminology adopted and the relationships identified, it is appreciated that the methodology is not yet finalised and that in particular there is much work yet to be done in providing the secondary aids and techniques to assist curriculum designers who apply the methodology ; the present programme of work of the Group is designed to produce at least some of this information.

Nevertheless, the Working Group believes that the curriculum design methodology which has now emerged from its deliberations offers, even in its present form, significant advantages to all those concerned with designing engineering curricula.

3b. THE CURRENT DESCRIPTION OF THE METHODOLOGY

The methodology represented graphically in figure 1 is a systematic sequential progression through four stages ; problem definition, curriculum synthesis, curriculum validation and implementation.

Each stage involves an iterative modelling process the output from which is evaluated prior to being forwarded as part of the input to the next stage. This basic, cyclic modelling process is illustrated in the legend in Figure 1.

For convenience, Figure 1 is presented as though curriculum design were a once and for all linear procedure, whereas in practice it is a highly iterative process which depends heavily upon previous developments and involves multiple secondary interactions. It also requires the frequent application of the procedure in the form of feasibility studies and the injection, at various stages, of the necessary elements of individual or collective expertise, enthusiasm and criticism.

The four stages involved in the overall curriculum design process are discussed in detail in the following sections.

3bi. Stage 1 - Problem definition

Stage 1 involves developing the statement of the problem, or qualification profile of the engineer to be produced, in terms of the educational aims and goals for the curriculum (or curricula). This requires a study of the societal, industrial, and professional needs and the use of the data obtained as input into a problem definition process from which the problem statement can be synthesised.

The societal needs survey involves the identification of the relevant short-term requirements and constraints of the society. In some countries a Government Agency or Commission formally attempts to match the flow of engineering graduates to the projected needs of the society; in others the results of broader demographic and socio-economic forecasting of regional and national needs are used directly by those developing course curricula.

Economic considerations form a crucial aspect of the assessment of societal needs. The economic necessity to develop particular industries or areas of expertise and the ability and willingness to invest the necessary capital and running costs are related and relevant inputs.

Industrial needs comprise an aspect of societal needs which is of particular importance to engineering curriculum design. The type (sector) of industry to be catered for, the number and nature of the graduates and particular national or regional needs, must all be identified and if possible quantified.

Professional requirements vary significantly from country to country in the extent to which they are specified and enforceable. However they can normally be identified in terms of the stipulated criteria for initial registration and for continuing registration of practising professional engineers.

Following the initial attempts to assess the true needs, the information obtained is subject to the problem definition process, during which an attempt is made to define boundaries and to identify further problem areas and any additional information which may be required. This is obviously a cyclic process which can be undertaken formally or informally by an individual or team. In any event, however, the overall process requires a considerable commitment by a number of experts if the outcome is to be a valid and realistic problem statement.

The nature of the problem definition process will depend upon the type of course being developed and the reliability and validity of the data available - an extrapolation development will not normally involve the major fundamental exercise which would probably be necessary in the case of a novel and radical proposal. For sound academic reasons, and to avoid pitfalls due to poor forecasting, it is considered advisable during the process and in the qualification profile, to emphasize goals dealing with learning ability, adaptability, intellectual capacity, skills and attitude, rather than to attempt to produce a limited vocational course.

In a situation of rapid and significant change the emphasis, at this stage of the overall curriculum design process, must be on objectives rather than course content or detail, as this will afford the opportunity later to incorporate the necessary degree of flexibility and adaptability.

The evaluation of the qualification profile concludes the problem definition stage and is an important element in the iterative process leading to the final problem statement ; it involves not only checking the conclusions in detail but also the process by which they were reached and the data upon which they were based.

The table presented in Figure 2, which is taken from Ref. 13, postulates a matrix of relationships which affords some guidance for the appraisal of the qualification profile. The elements of the qualification profile are considered in four aspects ; micro economic, macro economic, individual and social. Each of these elements is viewed differently by four groups in the community which are defined as the student, society, the economy (employer) and the scientific and technological interests.

The varying value systems which exist in countries with different idealogical and cultural contexts will obviously affect the specific relationships given in Figure 2 but the recognition of the needs to consider and define these relationships, and the technique described, should assist in the synthesis and evaluation of an appropriate qualification profile.

The overall method of evaluation of the qualification profile will relate to the way in which the problem statement has been produced. A national proposal may result in a paper for discussion, whereas a local proposal may be required to be submitted to a formal validation and approval procedure prior to further development. Experience suggests that an evaluation at this stage which involves a constructive dialogue between those responsible for producing the problem statement and an appropriate and expert group of assessors, is of considerable value in arriving at a definitive and realistic statement of objectives upon which the second stage curriculum synthesis can be based.

3bii. Stage II - Curriculum synthesis

Curriculum synthesis involves a study of the qualification profile together with data on teaching and learning methods, the applied constraints

and the accepted criteria, in order to synthesise a detailed curriculum proposal which is then evaluated and recycled until a satisfactory solution is evolved.

The studies so far undertaken by the Working Group into the teaching and learning methods generally available in engineering courses suggest that there is not yet any obvious correlation between teaching methods and the knowledge, skills and attitudes to be imparted and fostered. They also indicate that learning is a highly individual process which relates closely to the personality, ability and motivation of the student. However it is agreed that in the synthesis stage of curriculum design it is essential to give serious consideration to the types of teaching and learning methods to be used and to attempt to relate them to the curriculum content. It is recognised that this aspect of the work of the Group is not yet complete but it is hoped that its present programme of work will provide additional insights and guidance possibly by the further development in the form connected matrices.

The categories of constraints to be catered for include resources, and these involving students and academic considerations. Resource constraints include academic staff, support staff, specialist accommodation and facilities, general teaching accommodation and communal resources. This is one aspect of the curriculum design process which can be proceduralised to a major extent and for which the appropriate data can reliably be quantified although this is not, of course, just a matter of quantity, but is also a function of the effectiveness of the resources available. The efficiency of academic staff, for example, depends upon the teaching and assessment methods, the developing knowledge of teaching and learning in higher education and the extent to which staff and support materials are available to take advantage of these. Reference 4 presented to the Warsaw meeting includes examples of formalised procedures for the presentation of some of this information, and it is anticipated that the current studies of the Working Group into the presentation of selected Case Histories in engineering curriculum design will provide additional guidance on this aspect.

In considering the student constraints the first task is to make an assessment of the quantify, qualifications, experience and motivations of prospective students for the curriculum developments engisaged - both aspiring engineers and practising registered engineers. An attempt should then be made to determine the reaction of current and past students to curriculum content, choice, total study effort required, number of concurrent studies specified and the teaching and evaluation methods used.

The academic constraints which must be fed into the problem definition stage include factual information on admission requirements length of study, academic standards, classification of awards and balancing of course content.

The criteria used to resolved conflicts between constraints and to affect compromises during the curriculum synthesis process are often unconscious, are based on traditional methods and concepts and usually involve intuitive subjective decisions. It is important, when fundamentally reviewing curricula not to assume that any such criterion is sacrosanct but to attempt to identify and justify them all in terms of the real and prevailing situation. In cases where the stated objectives deviate little from those of a previous and successful scheme the curriculum synthesis process is mainly adaptive and only involves mofidying the existing proposal. In other cases, a more substantial and innovative effort is required.

The process is usually started by analysing, in the light of the problem statement, the gap between the starting knowledge and each of the knowledge goals in order to identify learning units which can be classified according to some suitable division of knowledge - for example, Engineering Science, Technology, Design, Mathematical Sciences, Industrial and Social Studies and Humanities. The learning units are then arranged to form a hierarchy of concepts, principles and facts according to the criteria of continuity, sequence and integration ; this not normally a difficult task as in most cases the same or a similar goal has been considered previously. The required time allocation, tutorial staff and the appropriate

resources are then considered and if necessary, some of the goals may be discarded and others added.

The next step is to choose a curriculum structure appropriate to the selected and specified objectives and to resolve such problems as : which areas of study should be mandatory and which elective; to what extent the student can select his own programme and still follow a consecutive, coherent course of study; the balance between technical, social and economic studies; the desirability of a combined programme of academic studies and industrial experience, the need for integrating studies.

Having effectively identified the syllabuses for most of the course, the objectives, teaching methods and methods of examination relating to each of them must be defined. This step is particularly important in ensuring that each of the possible curricula which may be developed at this stage, relate to the qualification profile in terms of the educational goals and the realisation of the skills and attitudes goals.

The evaluation of the possible curricula and the selection of the optimum involves the scrutiny of the schemes from the standpoint of satisfying the problem statement, assessing the teaching and learning methods and meeting the applied constraints and criteria. As with the evaluation of the qualification profile, this process is to some extent a continuous selective and cyclic procedure which comprises the iterative process leading to the selected curriculum proposal. The collation and suitable presentation of substantial and valid date in existing course content and structure which it is hoped will be provided by the pilot studies being undertaken by members of the Group should be of considerable value as part of the evaluation and selection process. The final step in the curriculum synthesis stage is to present the selected curriculum - syllabuses, structure, timetables, teaching methods and methods of examination to some clear and standardized format prior to the final validation. Reference 4 and the current ongoing programme of work of the Group are intended to provide some formal guidance in this respect.

3biii. Stage III - Curriculum validation

The nature and timing of the curriculum validation stage will vary with the type of engineering curriculum proposed and its context. The validation should, however, include a detailed and critical assessment process which will be concerned with the validity of the problem statement and the extent to which it is satisfied by the selected curriculum.

The critical assessment may vary between a formal concentrated personal confrontation between those responsible for the proposal and a team of assessors, and a longer term consultative approach. The assessors must include experts with the appropriate general and specialist knowledge and it is also considered important that the necessary information is presented to the assessors to an agreed and acceptable format.

The evaluation should cover the competence, commitment and methodology of those responsible for the proposed curriculum. In addition to the detailed analysis of the qualification profile and the proposed solution and the relationship between them, the assessors should also be concerned that all the relevant needs and constraints have been identified and satisfied. The course content, level, structure, teaching methods, assessment and general philosophy should all be rigorously assessed and related to the stated aims. Factors such as student choice, the availability of breadth and depth of study within a coherent course structure, possible transfers to and from other courses, classification of awards, demands for special resources and the adaptability provided within the proposal should all be included in the assessment.

The formal assessment procedure will often suggest minor improvements which can be readily incorporated ; it may occasionally lead to major reconsideration of the earlier stages in the overall curriculum design process. The output from the validation stage is the validated curriculum ; the detailed and stringent scrutiny to which it has been subjected should not only improve it and its credibility, but should also encourage its acceptance by those who will implement and undertake it.

3biv. Stage IV - Implementation

Although the implementation stage in curriculum design follows the successful validation process, it must still be accompanied by continuous monitoring and evaluation of the validated curriculum in action. This process can be regarded as the re-application of the curriculum design methodology with a continual re-appraisal of societal, industrial, educational and professional requirements, and the feedback of changes in student constraints and resource constraints (e.g. feedback relating to the effectiveness of teaching methods). Change in the curriculum to accommodate changes in the inputs will for the most part be made within the flexibility built into the curriculum but major changes may require re-application of the validation stage.

In order to be successful, the process of monitoring and evaluating the curriculum in action must be carried out formally. Course Boards, with staff and student representatives, should meet regularly to discuss and assess all aspects of the course and the curriculum. Advisory Committees comprising staff, ex-students, industrialists, educationalists and other experts should also be convened to receive reports on the course progress and to relate it to be latest local or national requirements. External Examiners may also be appointed to provide an objective and authoritative view - particularly of academic standards.

This formal and detailed monitoring process, and the inherent flexibility built into the curriculum, will enable the course content and modus operandi to be tuned continually towards meeting the latest changes in the requirements which the curriculum must satisfy. The data provided by this process will also indicate when it is necessary radically to revise the curriculum and will provide data which can be fed into the new curriculum design process.

3c. COMMENTARY ON THE METHODOLOGY

The preceding sections have described the evolution and latest version of a methodology of curriculum design which has been produced from

the meetings of the International Working Group and stemmed from that Group's recognition that the proceduralisation of data collation and injection in curriculum design, and the iterative nature of the overall process, were common to a wide range of situations and were fundamental characteristics of any methodology.

The Group has no doubt concerning the merit and value of a pragmatic methodology of curriculum design which is easy to use and is adaptable to a wide range of situations. A programme of work is being undertaken by members of the Group in order to develop the methodology further, to facilitate its use and to study the secondary aids and techniques associated with it. Nevertheless, it is considered that the overall methodology developed so far offers a realistic and positive assistance to all those concerned with engineering curriculum design.

4. CONCLUSIONS AND RECOMMENDATIONS

The meetings of the International Working Group on Curriculum Design in Engineering Education, have demonstrated a unanimous view that due to the continuing and rapid evolution of the scientific and technological basis of the work of engineers and their role in society, and the changing circumstances in society, industry and education, it is necessary continually to reappraise and revise engineering curricula.

From the studies presented by the participants, who represented a cross-section of the advanced and developing industrial nations, it was clear that no universal engineering curriculum could meet the variety of needs, constraints and contexts affecting engineering education and training. However, a substantial consensus did emerge that the principles and stages involved in curriculum design are sufficently common and definable to enable them to be structured to constitute a logical, sequential procedure and that this procedure could be systematised in order to produce a generalized methodology of engineering curriculum design.

With the encouragement and assistance of Unesco and its officers, the Working Group is evolving and describing such a generalized methodology which it believes will be sufficiently adaptable and easy to use to enable it to be applied to engineering curriculum design regardless of the stage of industrial development of its context. Because of the nature of the Working Group the methodology has been developed primarily for curricula design for professional engineers. However, the Group considers that the methodology developed is sufficiently general in nature to be applicable also to the design of curricula for the education and training of technicians.

The Working Group has closely studied the problems associated with any methodological approach and has been at pains to produce a procedure which can cater for the diverse, unpredictable and intuitive aspects of curriculum design without being disproportionate to the situation in which it is employed. At the same time it is considered that the methodology and associated aids which are being developed are formalised and proceduralised to an extent which provides a logical and converging route to

a satisfactory curriculum. It is recognised that the methodology is not yet finalised but believes that even in its present form it offers considerable advantages, particularly in establishing the real needs and objectives and in synthesising and accrediting a suitable curriculum to meet them.

A further important conclusion drawn by the Group is that, in spite of the advantages afforded by any methodology of curriculum design, the time taken to design and prove a successful engineering curriculum may still be of the same order of magnitude as the time scale of significant input changes. This means that it is essential to embody sufficient flexibility in the curriculum to enable it to be readily modified and adapted as input changes are identified and specified. The extent and nature of this inherent flexibility will vary with the circumstances.

During its programme of work the Group has identified the following areas of study related to engineering curriculum design, and the need to refine and improve the methodology.

1. A survey of existing literature on engineering curriculum design ;
2. Development and description of the methodology of engineering curriculum design ;
3. The relationship between engineering curricula and the teaching and learning process ;
4. The effect of inter-disciplinary courses on engineering curricula.
5. Specific needs and problems related to the design of engineering curricula in developing countries.
6. Specific problems related to the design of curricula for training higher technicians.
7. Practical training as an integral part of engineering curricula.
8. The compilation of case studies on the application of a methodology of curriculum design.

In some of these areas a considerable amount of work has already been done and the continuing programme involves only a process of monitoring and disseminating new information. In other areas however the Working Group

recognises that there is much work yet to be done if the principles and relationships which it has begun to identify and study are to be understood and applied effectively.

The provision of data on existing engineering curricula as an aid to the curriculum design process has been discussed by the Group and it has agreed that a pilot study of specified engineering disciplines will be undertaken by some of its members, with a view to establishing how such data should be collated and presented.

The Working Group agreed that not only it is important to develop information and methods aimed at improving engineering education throughout the world, but it is essential that positive steps are taken to promulgate this information. To this effect the Group have recommended that regional seminars under Unesco sponsorship should be organised on this subject.

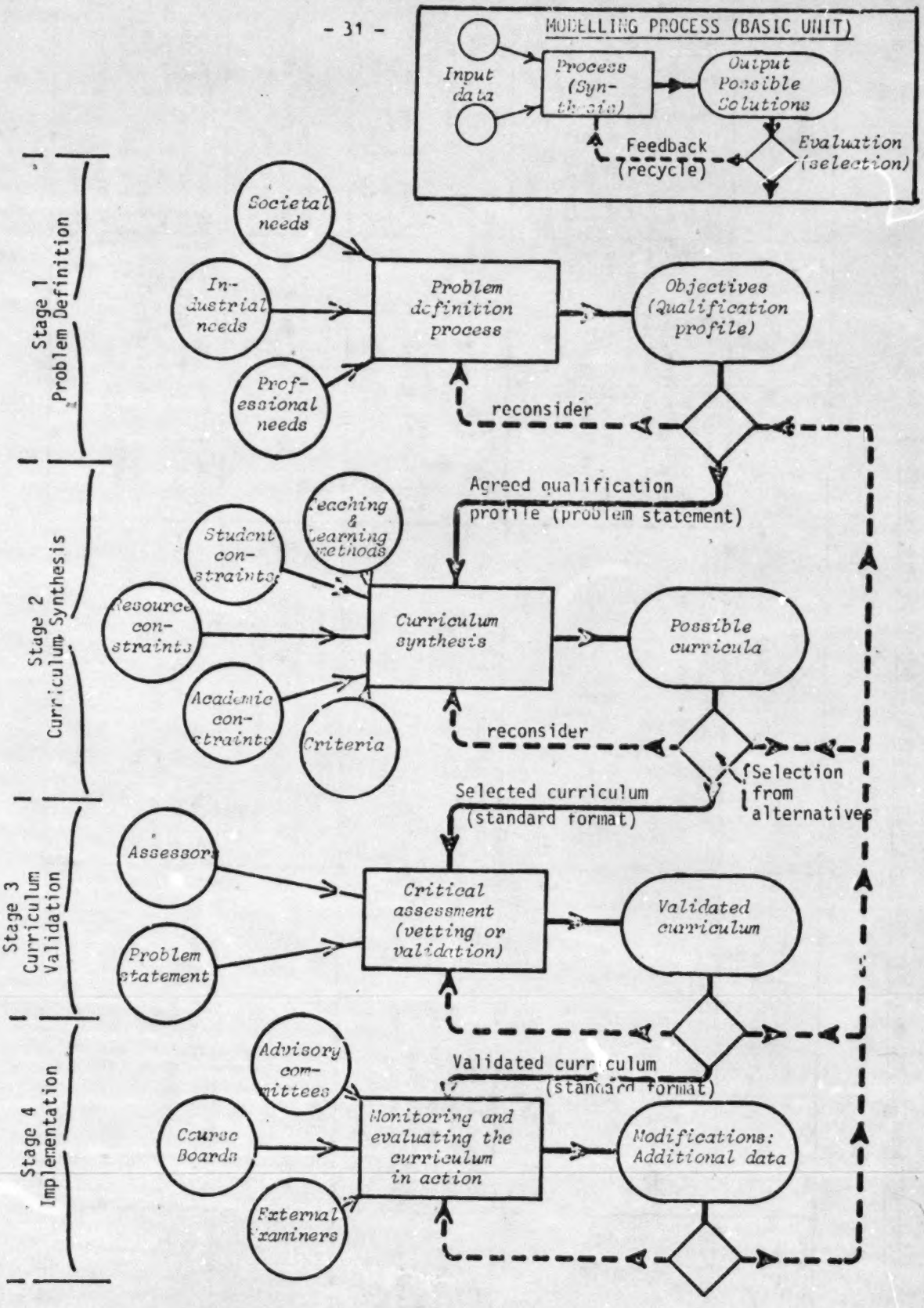

FIG.1. REPRESENTATION OF OVERALL CURRICULUM DESIGN

Fig. 2 - COMPILATION OF THE CRITERIA FOR THE APPRAISAL OF THE QUALIFICATION PROFILE ELEMENTS

Groups \ aspects of advantage	micro economic aspect (the company)	macro economic aspect (the industry-economy)	individual aspect (the person)	social aspect (the society)
Economy	profit maximization, economic efficiency, stability of the company	efficiency of the total economy, economic stability	stress stability, psychic health, mental flexibility, work motivation, identification with the task, integrity towards the company, subordinative and physical capacity	influence of economy on public life, attractiveness of industry for the public relative to recruiting, level recognition of economy in the social system of value
Students, engineers	chances of making one's way in the company, position in the company, salary, job security independent of structural changes of the branch	labour market of a professional group	right of co-decision, reputation, prestige, independence, self-realization, life quality, mobility	image of the profession in public. Positive influence of a group of profession, living standard of a group of profession
Society	stability of the company , economic efficiency of the company	job security, protection against structural deviations of the branch, environmental protection, ecomic efficiency	self-realization, codecision, emancipation, mobility, innovation frankness	quality of life, environmental protection, democratization innovation frankness
Science	privileged treatment of science in the company (basic research)	public claim of science, claim of the coming engineering generation, recognition of science as a productive force	economic efficiency, economic output, motivation for purely scientific activity, scientific qualification	recognition of science as intrinsic value, recognition of science as creative power, claims of the coming engineering generation

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